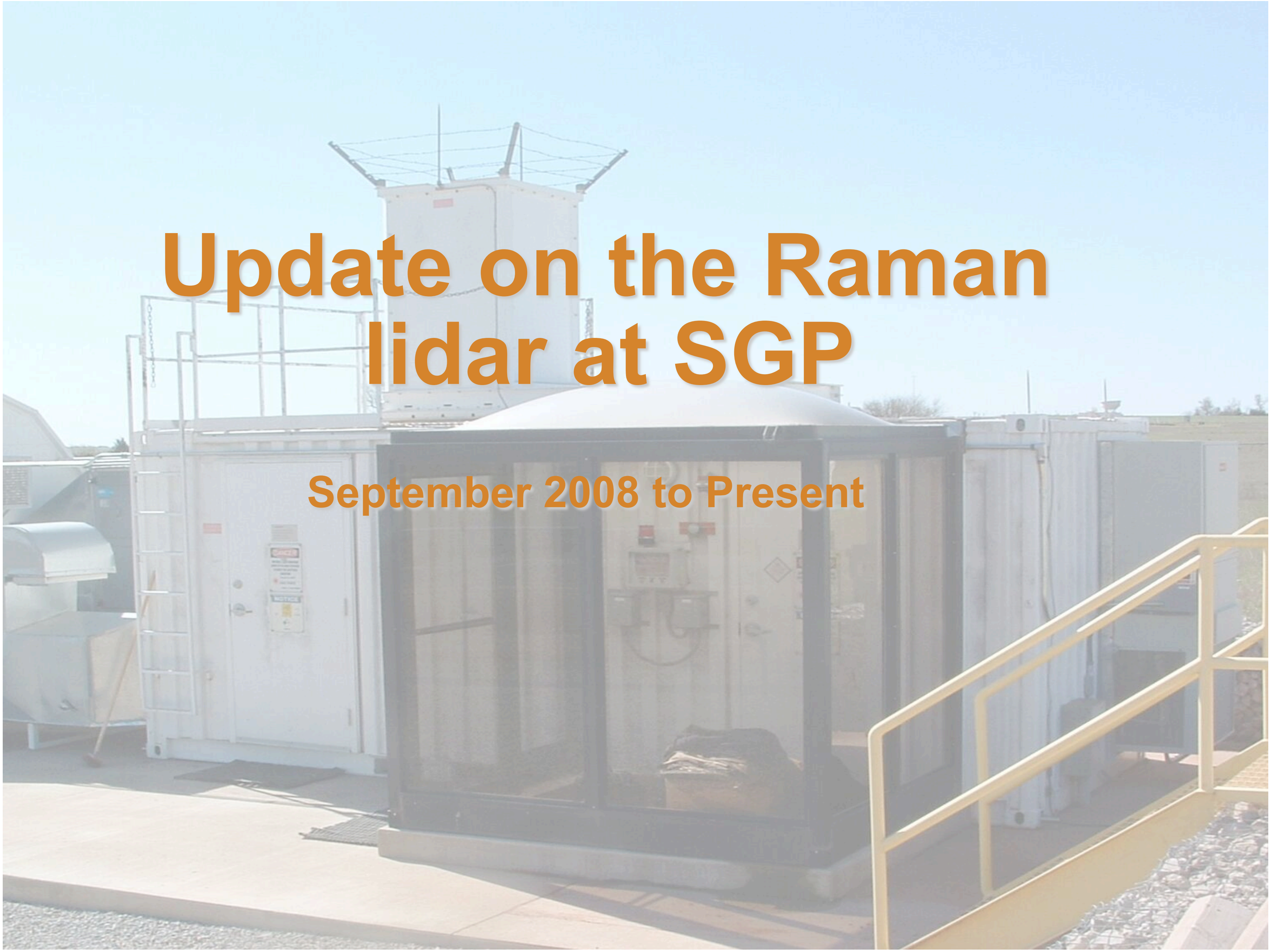
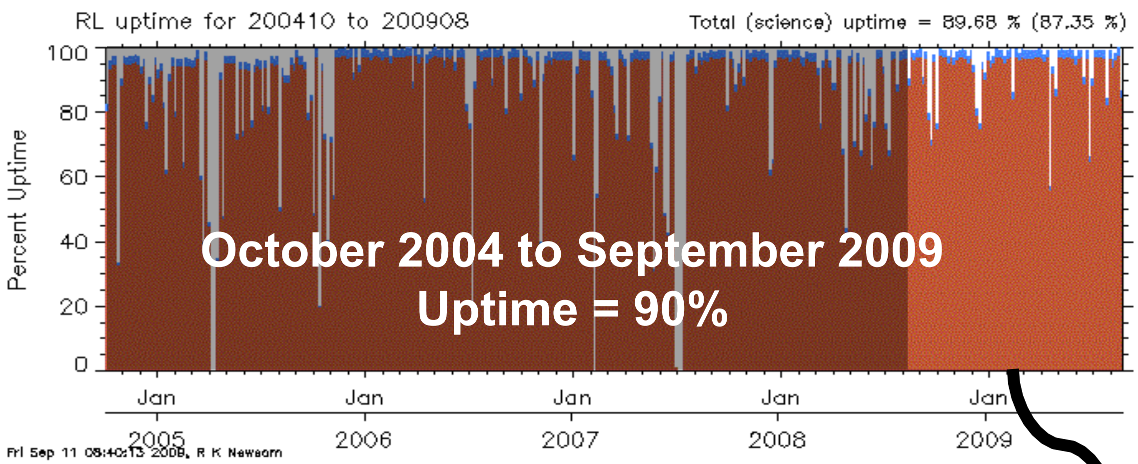
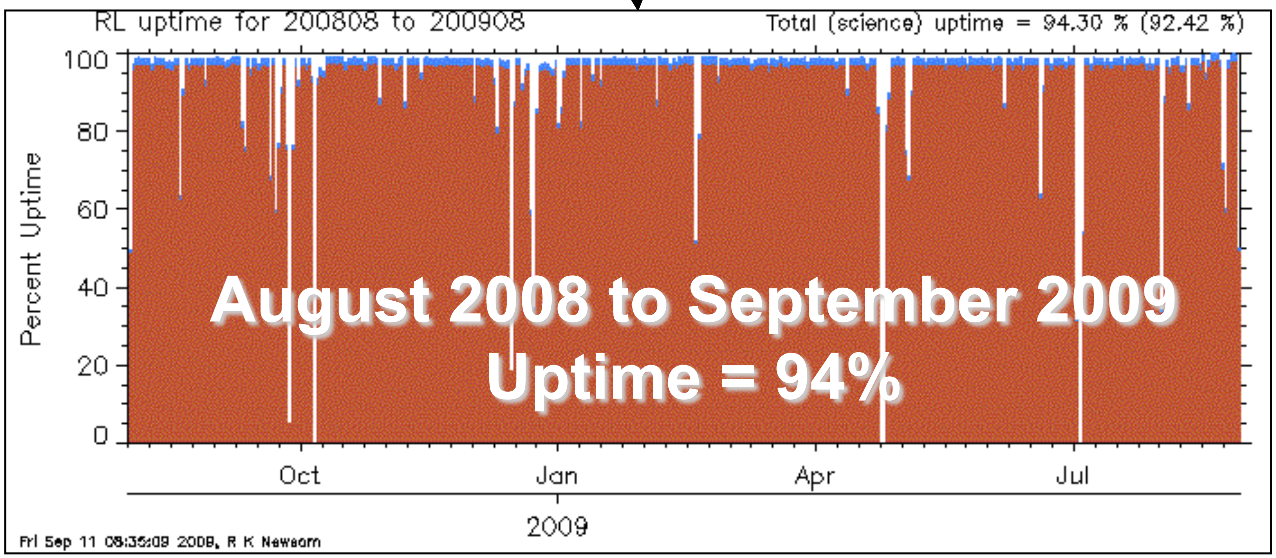
Update on the Raman lidar at SGP

September 2008 to Present



Raman Lidar Uptime





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Raman Lidar Hardware Issues

Filter Wheel for the WFOV channel (CVI Model AB301)

- Comes out of proper alignment and obscures beam
- Must be checked every day or so
- Degraded sensitivity due to obscuration or incomplete beam blocking for mode 0 data.
  - degraded sensitivity in July and beginning of August ’09
  - degraded sensitivity in March and early April ‘09.
  - Invalid mode 0 data from 12 November ‘08 to 12 January ’09 (This required a modification to the Merge VAP)
- New unit will be ordered with ARRA funds.

Laser pulse energy monitior

- False readings resulted in frequent shuts downs in April and May. Problem was fixed by reseating connectors, i.e. wiggling wires.
- New unit will be ordered with ARRA funds.

Thermal Cycling Issues (next two slides)

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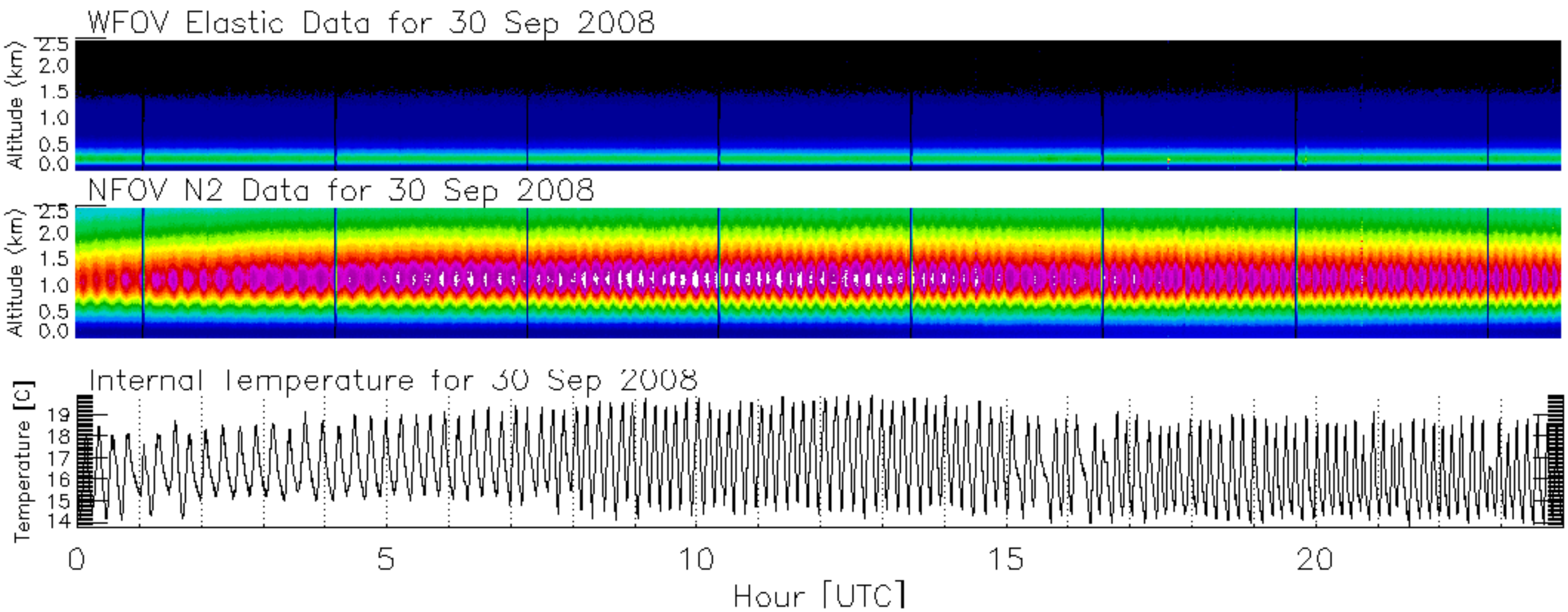
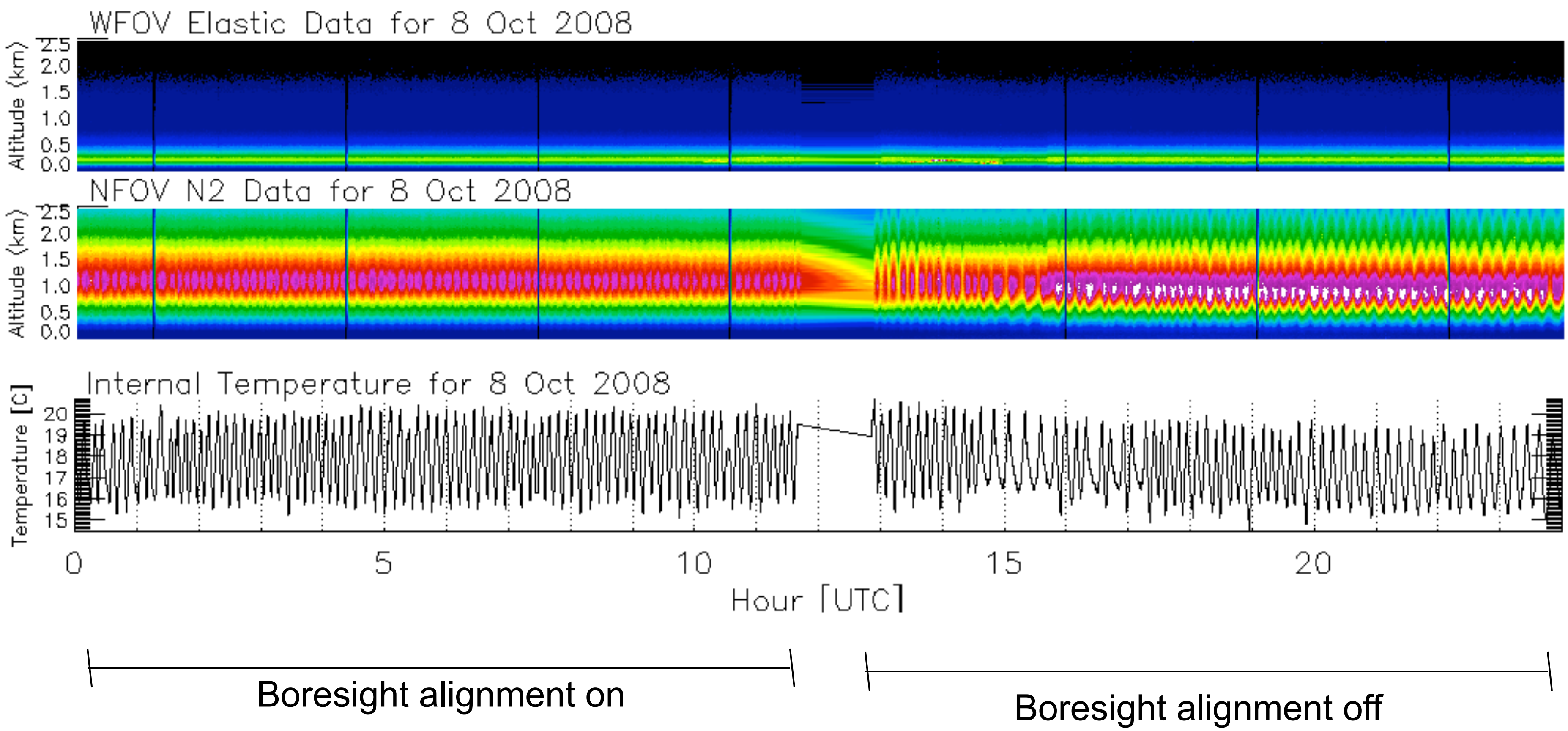
Thermal Cycling Effects (caused by the AC)



Boresight Alignment was active during this period. Thermal cycling effects would have been even worse otherwise.

Thermal Cycling Effects Reduced by Shielding the Telescope and AFT Optics



VAPs: Data Availability

MERGE

- 20041001 to 20090831 is in the archive
- 20090901 to present is pending review

Aerosol Scattering Ratio/Backscatter

- 20041001 to 20050731 needs overlap correction
- 20050801 to 20050831 no release due to poor quality
- 20050901 to 20051223 is pending release
- 20051224 to 20060531 is in the archive
- 20060601 to 20070331 is pending release
- 20070401 to 20090531 is in the archive
- 20090601 to present is pending release

Aerosol Extinction/AOD

- 20041001 to 20050731 needs overlap correction
- 20050801 to 20050831 no release due to poor quality
- 20050901 to 20090228 is in the archive
- 20090301 to present is pending release

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VAPS: Data Availability (continued)

Water Vapor Mixing Ratio

- 20041001 to 20050731 needs overlap correction
- 20050801 to 20050831 no release due to poor quality
- 20050901 to 20090531 is in the archive
- 20090531 to present is pending release

Aerosol Depolarization Ratio

- 20041001 to 20070331 is not yet processed
- 20070401 to 20080831 is in the archive
- 20080901 to present is pending release

Temperature

- Operational processing not yet started

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Temperature VAP

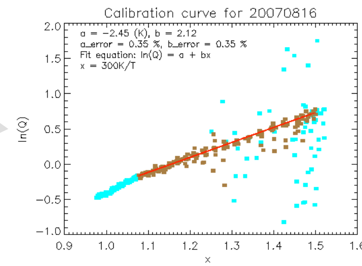
The temperature VAP uses the two NFOV rotational Raman channels (at 353 and 354 nm) to estimate temperature profiles

- Calibration
  - Nonlinear
  - Uses radiosonde data at SGPC1
  - Time dependent calibration coefficients

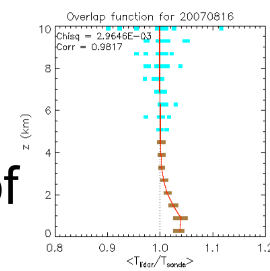
$$Q = S_{354} / S_{353}$$

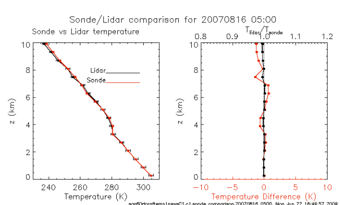
$$\ln Q = a + bx$$

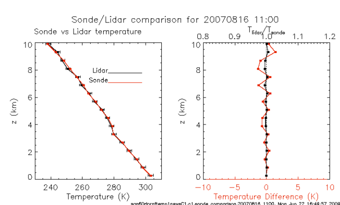
$$x = 300K / T$$

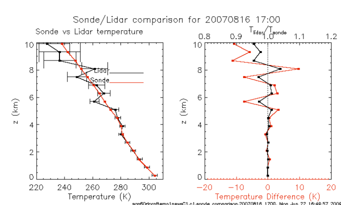


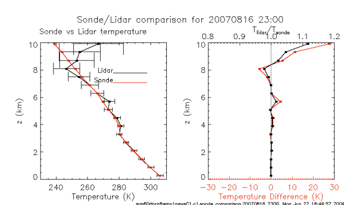
- Overlap correction
  - Fully automated overlap correction process
  - Uses radiosonde data at SGPC1
  - Fits ratio of lidar-to-sonde data using an expansion of basis functions with time dependent coefficients











Temperature VAP Status

- Currently tested on 6 months of data (April through September 2007)
- Before releasing this VAP into production we should …
  - Run over longer period
  - Compare temperature profiles against independent data source, e.g. AERII

A Few Other Noteworthy Things

- RL Handbook has been revised and updated
- Depolarization VAP was released into production
- Paper on MERGE improvements was published.
  - Newsom, R.K., D.D. Turner, B. Mielke, M. Clayton, R. Ferrare and C. Sivaraman (2009). The use of simultaneous analog and photon counting detection for Raman Lidar. *Applied Optics*, **48**, 3903-3914
- The MERGE VAP is being Streamlined and updated
- Working to release the Best Estimate and Temperature VAPs

A Few Other Noteworthy Things (continued)

Raman Lidar #2

- Purchased with ARRA (stimulus) money
- Currently under development at Sandia in Livermore, CA
- Will be deployed to TWP-Darwin in 2010
- Essentially a copy of the existing system at SGP RL (minus the liquid water channel)

Raman Lidar #2 Development Status at Sandia

Long-lead items are being procured

- Enclosure
  - Orca Photonics only respondent to RFP
  - Orca built the enclosure for the SGP system
  - First design review held at the end of August ’09
  - Orca has some ideas about reducing thermal cycling in the enclosure
- Laser
  - “Expressions of interest” were received from 2 vendors on 20090910.
  - Final RFQ has been sent to the two vendors

- Electronics and data system
  - “Expressions of interest” have been received from 2 vendors
  - RFQ in preparation

New Doppler Lidar Remote Sensing Capability at ACRF

Atmospheric Radiation Measurement
CLIMATE RESEARCH FACILITY
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A Little Background

In 2009 ACRF received stimulus money for instrument acquisitions and upgrades. A significant portion of these funds are being used to acquire new advanced lidar systems for all of the ACRF sites. Efforts are currently underway to develop the following systems:

- One Raman lidar for TWP-Darwin
- Two High Spectral Resolution Lidars (HSRL) for NSA-Barrow, and AMF2
- Three Doppler lidars for SGP, TWP-Darwin, and AMF1

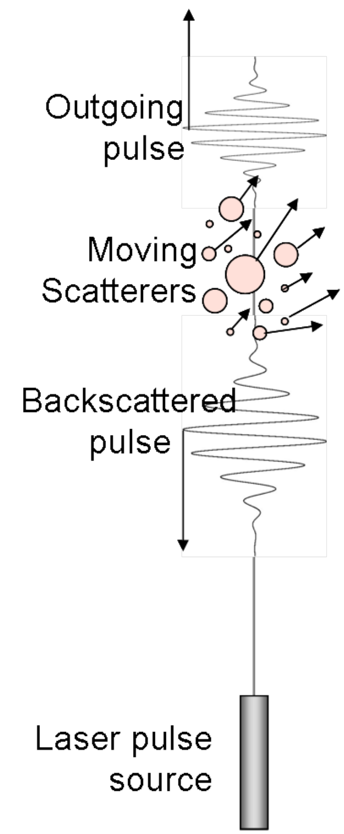
The purpose of this presentation is to discuss the Doppler lidars and their application

Doppler Lidar

- Doppler lidars provide time and height resolved measurements of the radial (line-of-sight) component of air velocity and (molecular and/or aerosol) backscatter.

- Radial velocities are determined from the frequency shift of the backscattered pulse relative to the outgoing pulse. $u_r = \lambda \Delta f / 2$

- Two types of systems
  - Incoherent or direct detection Doppler
  - Coherent Doppler



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Coherent vs Incoherent Doppler Lidar

- Incoherent
  - Doppler shift is measured directly using optical interference techniques
  - Can operate in visible and UV
    - Sensitive to aerosol and molecular backscatter
    - Not restricted to the boundary layer
  - Very difficult to measure small (wind induced) frequency shifts (~1MHz)
    - Long averaging times required
    - Large measurement errors
  - No commercially available systems.

- Coherent
  - Doppler shift is measured using heterodyne detection (as in radar)
  - Speckle effects limit application to longer wavelengths, i.e. IR.
    - Sensitive to aerosol backscatter, insensitive to molecular backscatter
    - Restricted primarily to the boundary layer
  - Very sensitive detection technique
    - short averaging times (~1 sec)
    - measurement errors on the order of 10 cm/sec.
  - Several commercial systems are available

Remainder of talk will focus exclusively on COHERENT systems

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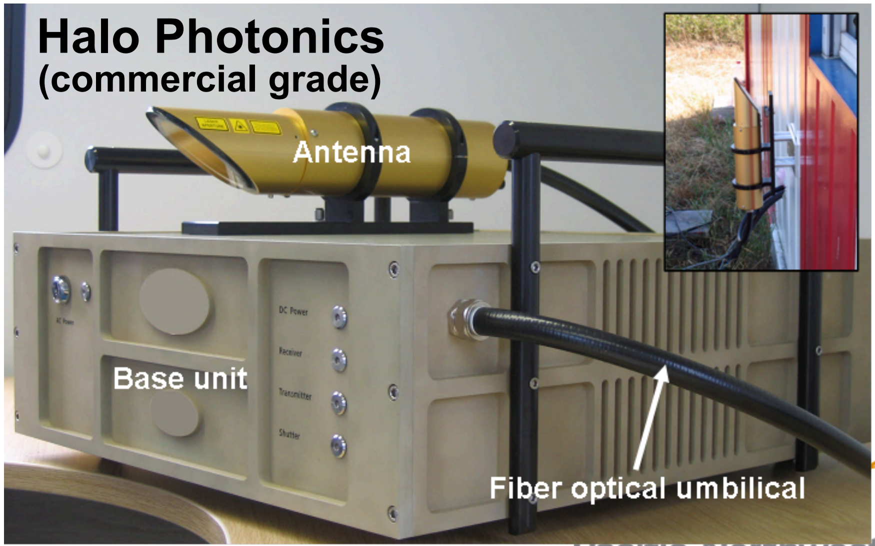
Examples of Specific Coherent Doppler Lidar Systems



And others…

ACRF Doppler Lidar System Specs

Major Performance Specifications

- Eye safe
- Vertically pointing (w/option for scanning)
- Data products: radial velocity, SNR, Doppler spectra
- Range: 100 m to 10 km
- Pulse width < 30m (pulse duration <200ns)
- Temporal Resolution (after averaging) < 1 s
- Velocity Precision < 20 cm s-1
- Mass < 2000 kg
- Volume < 10 m3
- Power consumption < 3kW, 120 or 240 VAC, single phase
- Delivery in December of 2010

Request for Proposal (RFP)

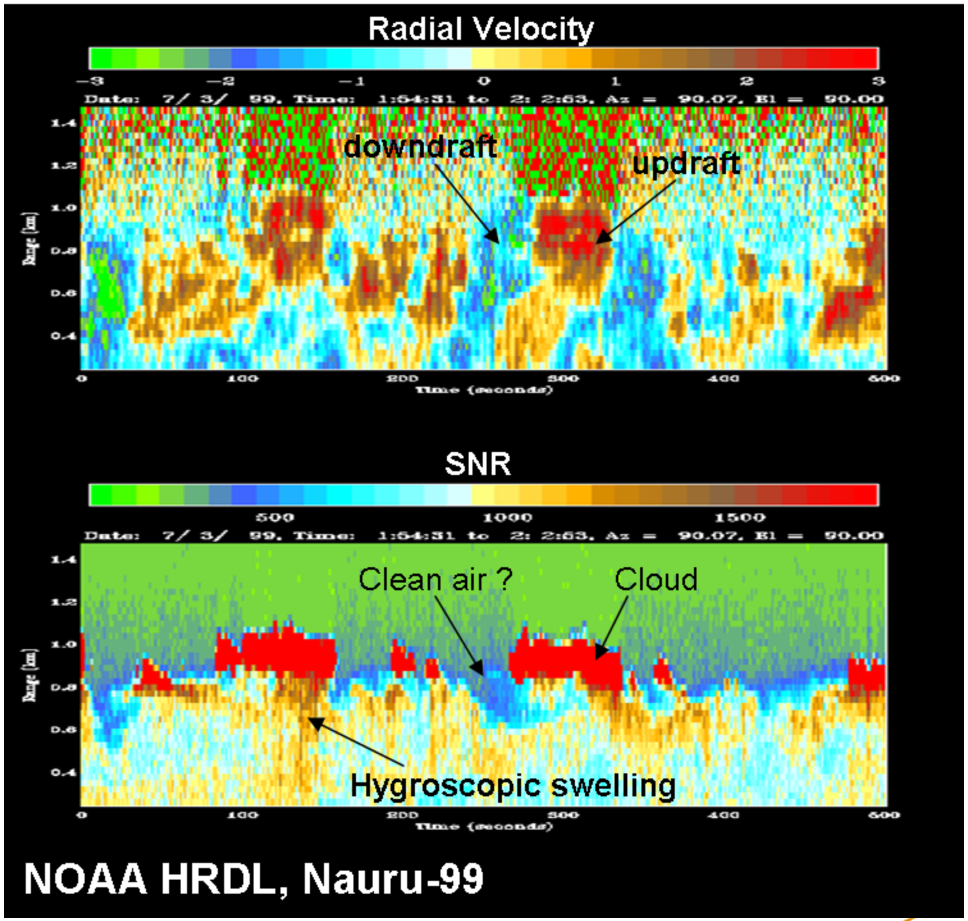
- Posted on the PNNL external site and FBO on 3 September 2009
- Sent directly to seven (7) prospective vendors
- Two vendors responded with proposals
- A vendor has been selected

Value Added Data Products

- Basic Measurements (100 m to PBL top @ Δt~1-10 sec, Δz~50m)
  - Vertical Velocity
  - SNR
  - Doppler spectra
- Possible derived data products
  - Profiles of attenuated backscatter
  - CBH
  - PBL height, zi
  - Profiles of spectral width
  - Profiles of vertical velocity statistics
    - Variance, skewness, kurtosis
    - Integral length scales
  - Turbulence power spectra
- Possible merged data products
  - Vertical velocity from cloud radar (in-cloud) with vertical velocity from lidar (clear-air)
  - Vertical water vapor flux (Raman-Doppler)
  - And more…

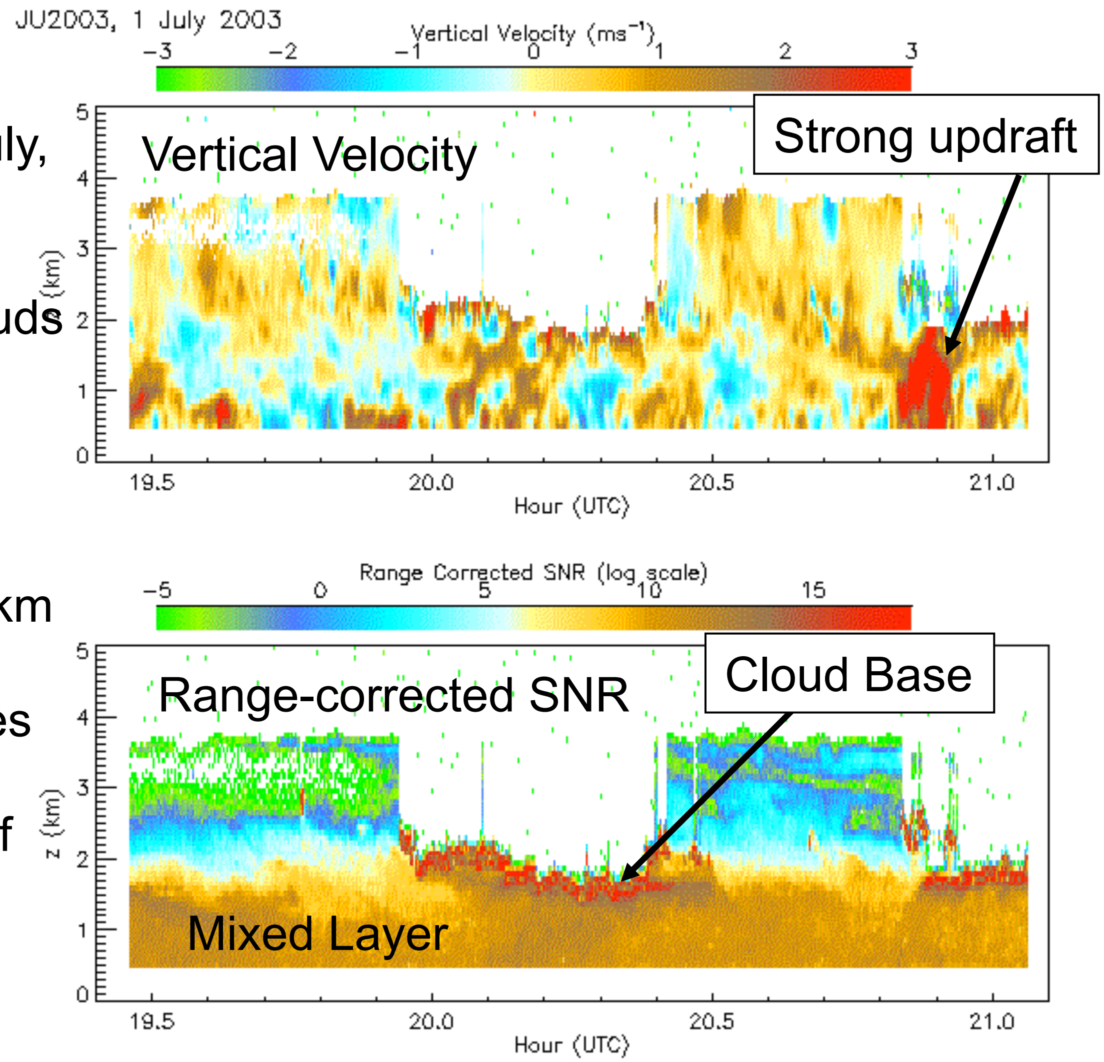
Examples of Vertical Velocity and SNR Measurements from NOAA's HRDL During Nauru99

- HRDL was deployed aboard the Ron Brown
- Early afternoon of 3 July 1999 w/ cumulus (CBH = 800 to 900 m ASL)
- Updrafts beneath clouds with max velocities of ~3 ms-1.
- Lower SNR in regions between clouds with strong down-drafts due to:
    - transport of cleaner air from above or
    - Particle shrinking due to decreased RH
- Enhanced backscatter below cloud base suggests hygroscopic swelling



Examples of Vertical Velocity and SNR Measurements from Lockheed's WindTracer During JU2003

- Oklahoma City, afternoon of 1 July, 2003
- Light winds w/small cumulus clouds (CBH ~ 1.5-2.0 km)
- SNR indicates
  - Mixed layer below ~2km
  - Stratified structure above 2 km
- The vertical velocity field indicates significant vertical motion below cloud base level, with a couple of updrafts exceeding 3 ms-1.



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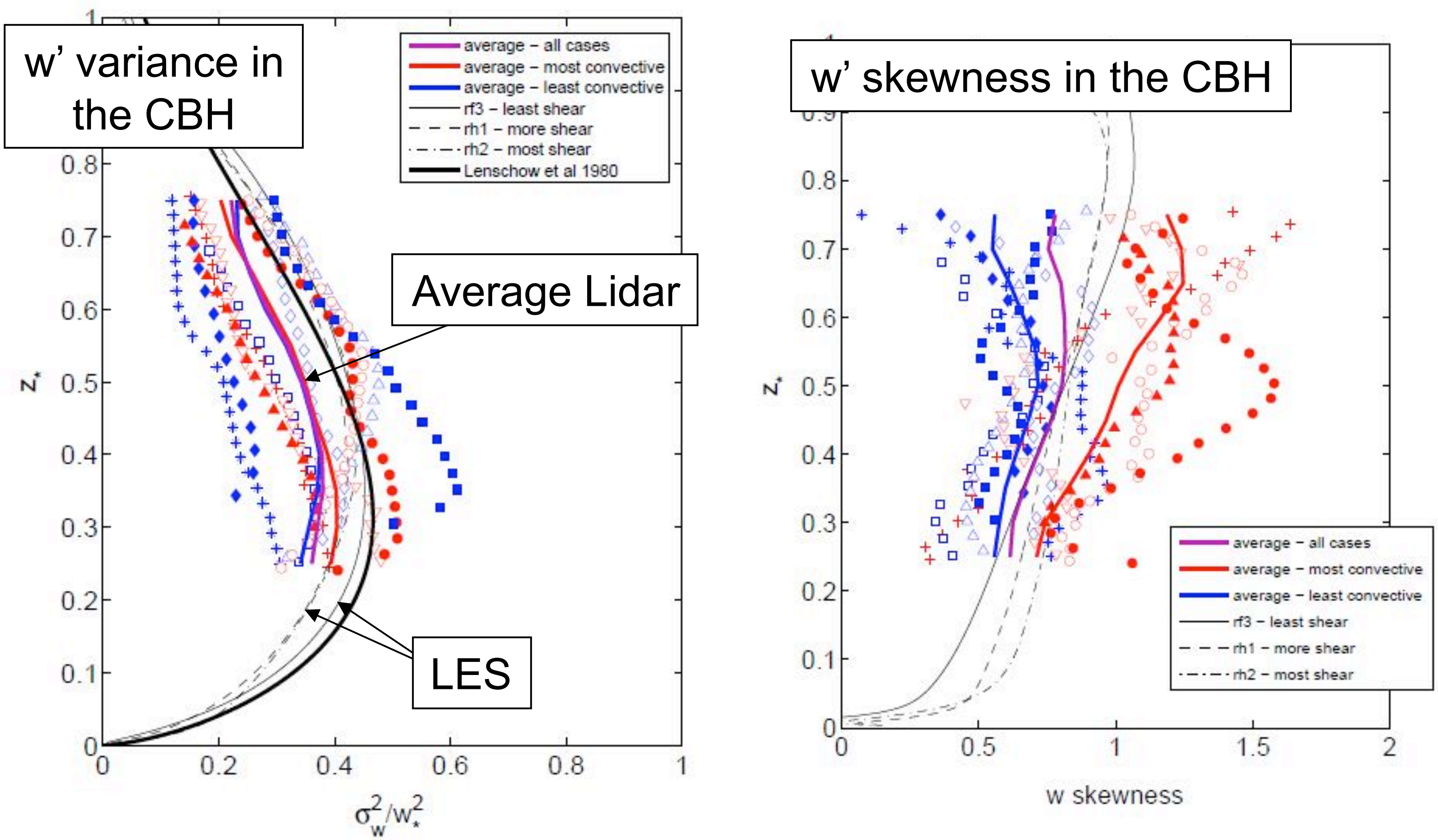
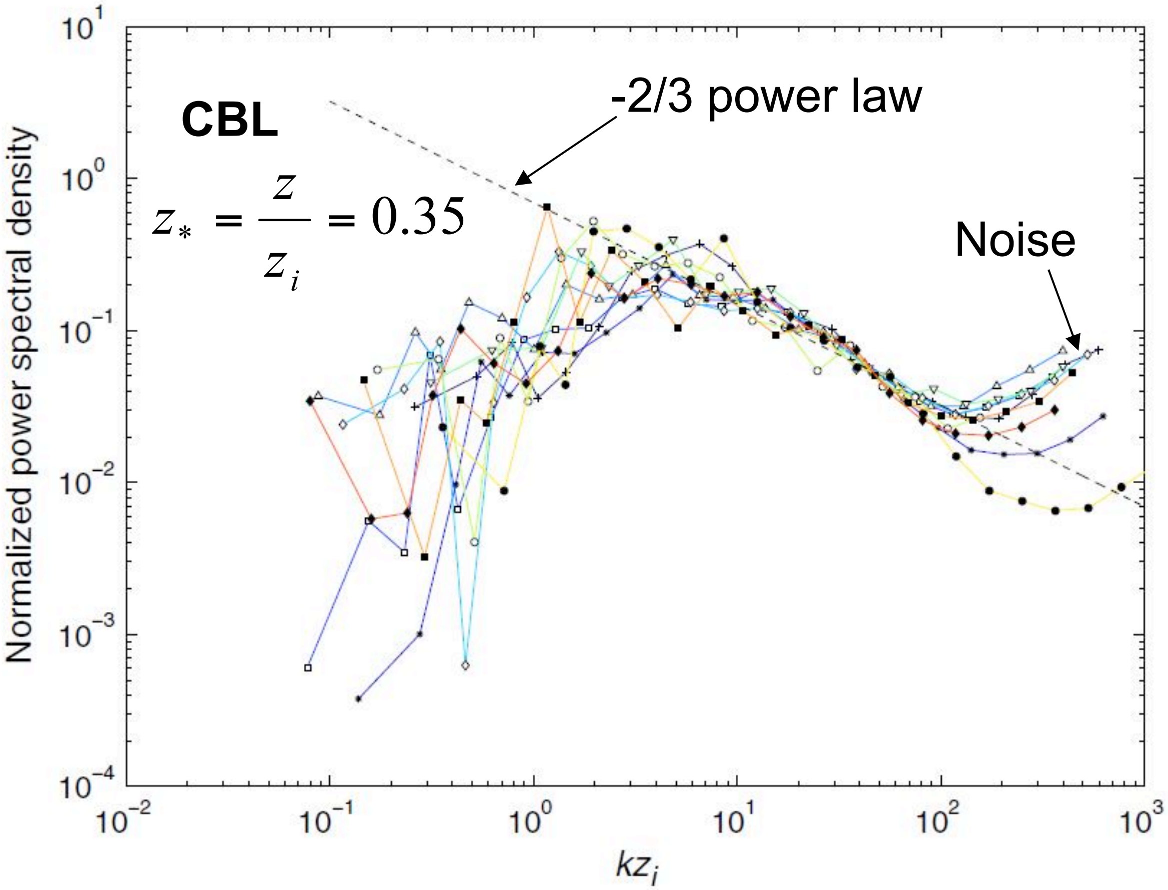
Statistics Derived from Lidar Vertical Velocity Measurements – Comparison to LES



Lenschow D. H., M. Lothon, S. D. Mayor, 2009 Doppler lidar measurements of higher-order vertical velocity statistics in the convective boundary layer. *4th Symposium on Lidar Atmospheric Applications, 89th American Meteorological Society Annual Meeting*, Phoenix, AZ.

Power Spectra Derived from Lidar Vertical Velocity Measurements



Normalize Power Spectral Density =

$$\frac{kS(k)}{w_*^2 \psi_\varepsilon^{2/3}}$$

where

$$\psi_\varepsilon = \frac{\varepsilon z_i}{w_*^3}$$

Lothon M., D. H. Lenschow, S. D. Mayor, 2009: Doppler Lidar Measurements of Vertical Velocity Spectra in the Convective Planetary Boundary Layer Boundary-Layer Meteorol. 132, 205–226.

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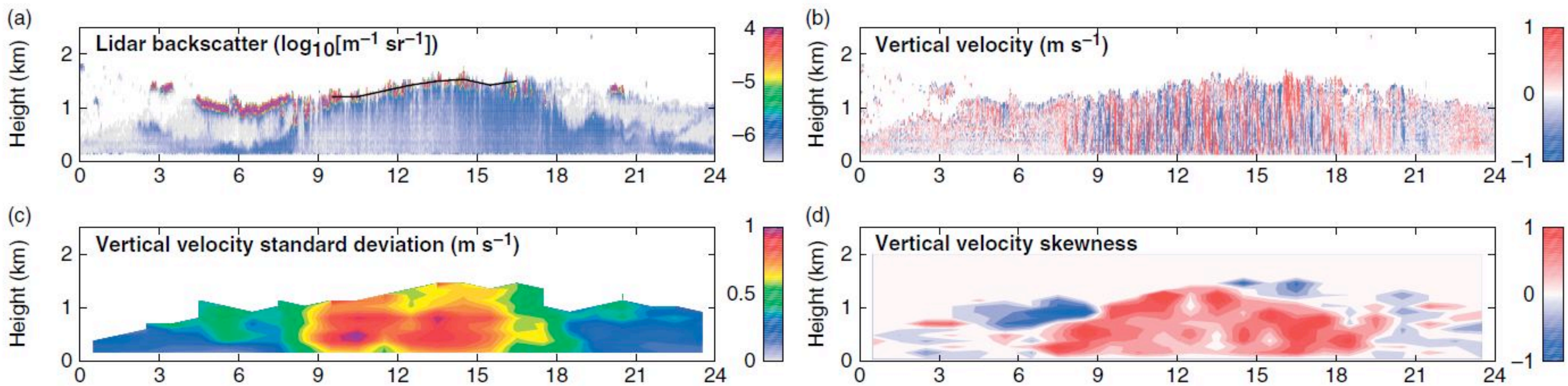
Examples of value-added products from the Chilbolton Observatory

Halo Photonics Doppler Lidar



R. J. Hogan, A. L. M. Grant, A. J. Illingworth, G. N. Pearsonb and E. J. O'Connor, 2009: Vertical velocity variance and skewness in clear and cloud-topped boundary layers as revealed by Doppler lidar. Quarterly J Royal Met. Soc., **135**, 635-643.

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Summary

- Procurement of three Doppler lidars is underway
- Proposals were received from two vendors (on 21 September)
  - Technical review has been completed
  - A vendor has been selected
  - Scanning option WILL BE INCLUDED
- Delivery scheduled for December 2010
- Systems will be installed at SGP, TWP-Darwin, and AMF1
- These instruments will help fill a long-standing measurement gap within ARM by providing time and height resolved measurements of vertical velocity through the depth of PBL, as well as in elevated aerosol layers and optically thin clouds.